U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: PROTECTION OF AIRCRAFT ELECTRICAL/ ELECTRONIC SYSTEMS AGAINST THE INDIRECT EFFECTS OF LIGHTNING
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Change:

1. PURPOSE. This advisory circular (AC) provides guidance on how to comply with the requirements of the Federal Aviation Regulations (FAR) relating to protection of aircraft electrical systems from the effects of lightning. It describes acceptable methods of compliance with the regulations applicable to all categories of airplanes and rotorcraft. This material is advisory in nature; it is not mandatory. Applicants for Federal Aviation Administration approval may elect to demonstrate compliance through alternative methods found acceptable by the FAA.

2. SCOPE. This AC provides guidance for a means of showing compliance with the regulations for protection against hazards caused by the lightning environment to flight critical/essential electrical/electronic systems installed either on or within aircraft. This document incorporates information and references relevant to providing: (1) acceptance criteria/protection levels, (2) protection (hardening approaches) against the indirect effects of lightning, and (3) verification methods. Equipment hazards addressed include those due to indirect effects on equipment and its associated wiring that is mounted on the aircraft exterior as well as indirect effects on equipment and its associated wiring located within the aircraft interior. This document applies to new aircraft and equipment designs, modifications of existing aircraft or equipment, and applications of existing (off the shelf) equipment on new aircraft. Applicable subsystems addressed include, but are not limited to, power distribution and generating equipment, electronic and electromechanical devices, electronic engine and flight controls as well as associated interconnecting wiring and/or cables.

Note: This AC does not address direct effects such as burning, eroding or blasting of aircraft structure nor does it address fuel ignition hazards. Fuel ignition hazards are addressed in AC-20-53 (latest revision), "Protection of Aircraft Fuel Systems against Fuel Vapor Ignition Due to Lightning."

3. RELATED FAR SECTIONS. Parts 23, 25, 27, & 29; Sections .581, .610, .867, .901, .903, .954, .1301, .1309, .1315 (pending) and .1431 (as applicable).

4. RELATED READING MATERIAL. A comprehensive discussion on the material in this advisory circular, with additional nonregulatory guidance information, is available in the following document: User's Manual for AC 20-XX, "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning," Report Number DOT/FAA/CT-88/1 (to be issued).

Test procedures and test conditions applicable to airborne equipment can be found in Radio Technical Commission for Aeronautics (RTCA) Document DO-160 (latest revision), "Environmental Conditions and Test Procedures for Airborne Equipment," Section 22, "Lightning Induced Transient Susceptibility." A copy of this document can be obtained from the RTCA, One McPherson Square, Suite 500, 1425 K Street Northwest, Washington, D.C. 20005.

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1. BACKGROUND.

a. Concern for the vulnerability of aircraft flight critical/essential systems to atmospheric electricity hazards has increased substantially. Aircraft which utilize an increasing number of electrical/electronic systems are currently being, and will continue to be certified. Two significant factors that have contributed to this increased concern are:

(1) Widespread use of sensitive electronics to perform flight critical/flight essential functions, and

(2) Reduced electromagnetic shielding afforded aircraft systems by advanced technology airframe materials.

b. Atmospheric electricity interaction with an aircraft can result in numerous problems. For the case of lightning, physical damage (direct effects) can result from a lightning attachment to the aircraft. Additional effects may result when the fast changing electromagnetic fields produced by a direct strike couples voltage and current transients into the electrical/electronic equipment or components. These transients can be produced by electromagnetic field penetration into the aircraft interior or by structural IR (current times resistance) voltage rises due to current flow on the aircraft, and are referred to as indirect effects.

c. The trend toward increased reliance on electrical/electronic systems for flight and engine control functions, navigation, and instrumentation requires that effective lightning protection measures be designed and incorporated into these systems. Reliance upon redundancy as a sole means of protection against lightning effects is generally not adequate because the electromagnetic fields and structural IR voltages can interact concurrently with all electrical wiring aboard an aircraft.

2. DEFINITIONS. See Appendix I for list of definitions.

3. APPROACHES TO COMPLIANCE. The following seven (7) activities are elements of an iterative process for designing and verifying protection of aircraft electrical/electronic systems against the effects of lightning. The particular order of activities addressed, and the iterative application of the elements appropriate for a particular situation, is left to the applicant and strict adherence to the particular ordering of the elements in the list is not intended.

ELEMENTS OF LIGHTNING PROTECTION DESIGN AND VERIFICATION

Determine the lightning strike zones for the aircraft.

Establish the external lightning environment for the zones.

Establish the internal environment.

Identify aircraft flight critical/essential systems, equipments, and locations on or within the aircraft.

Establish transient control levels (TCL) and equipment transient design levels (ETDL).

Design protection.

Verify protection adequacy.

The elements are described in more detail in paragraphs a. through g.

a. Determine the lightning strike zones for the aircraft. The characteristics of currents entering the aircraft vary according to the attachment point locations on the aircraft. To establish the lightning characteristics appropriate for different portions of the aircraft, lightning strike zones have been defined as follows:

(1) Zone 1A: Initial attachment point with low possibility of lightning channel hang-on.

(2) Zone 1B: Initial attachment point with high possibility of lightning channel hang-on.

(3) Zone 2A: A swept stroke zone with low possibility of lightning channel hang-on.

(4) Zone 2B: A swept stroke zone with high possibility of lightning channel hang-on.

(5) Zone 3: Those portions of the aircraft that lie within or between the other zones, which may carry substantial amounts of electrical current by conduction between areas of direct or swept stroke attachment points.

Zones are the means by which the external environment is applied to theaircraft. The locations of these zones on any aircraft are dependent on the aircraft's geometry, materials and operational factors, and often vary from one aircraft to another; therefore, a determination must be made for each aircraft configuration. Guidance for location of the strike zones on particular aircraft is given in Appendix II.

b. Establish the external lightning environment for the zones. The external lightning environment is a consequence of the interaction of the lightning flash with the exterior of the aircraft. The external environment is represented by the lightning current components at the aircraft surface as defined by the synthesized waveforms in Appendix III. Application of the various current waveforms with respect to the zones described above is noted in Table 1 of Appendix III.

Current flow paths through the airframe and around apertures are derived from aircraft lightning zones. Zones 1 and 2 define where lightning is likely to attach, and, as a result, the entrance and exit points for current flow through the vehicle. By definition, Zone 3 areas carry lightning current flow between pairs of direct or swept stroke lightning attachment points. Therefore, design and analysis using Zone 3 current levels as the external environment is generally acceptable.

c. Establish the internal environment. The internal lightning environment, which is produced by the external environment, is a result of current flow through the airframe and the penetration of electromagnetic fields. The fields and structural IR voltages constitute that portion of the internal lightning environment that causes the voltages and currents on interconnecting wiring which, in turn, appear at equipment interfaces. In some cases, electromagnetic fields within the aircraft may penetrate equipment enclosures and compromise system operation. A further discussion of lightning interaction with electrical/electronic systems is given in Paragraph 4.

d. Identify the aircraft flight critical/essential systems and equipment, and their locations on or within the aircraft.

(1) Identify the aircraft systems and/or line replaceable units (LRU) that may be affected by lightning, and whose proper operation is critical or essential to the operation of the aircraft. Determine equipment locations within the aircraft and the routing of wiring between LRUs.

(2) Determine if any of the critical/essential system(s) and equipment(s) could be damaged by direct lightning effects. Equipment mounted outside the protective structure of the aircraft should be protected from both the direct and indirect effects of lightning.

e. Establish TCL and ETDL. For each critical/essential system, determine the lightning induced voltage and current waveforms and maximum amplitudes that can appear at the electrical/electronic equipment interfaces. In many cases, the induced transients will be defined in terms of the open circuit voltage (e_{oc}) and the short circuit current (i_{sc}) appearing at wiring/equipment interfaces. The "e" and "i" will be related by the source impedances (i.e., loop impedance) of interconnecting wiring, and there may be different levels determined for different circuit functions or operating voltages. A discussion concerning the voltages and currents that can be induced by lightning is given in Paragraph 4. After determining the actual waveforms and amplitudes expected to appear in particular systems, the waveforms/levels defined in Appendix IV may be utilized to establish TCL and ETDL for systems and equipment protection.

The equipment transient susceptibility level is the amplitude of voltage or current which, when applied to the equipment, will result in damage or upset, such that the equipment can no longer perform its intended function. This level need not be quantified, but it will be higher than the ETDL, which represents the amplitude of voltage and/or current that the equipment is required to withstand or tolerate and remain operational (e.g., no damage or systems functional upset). The ETDL, in turn, will be set higher than the maximum amplitude of transients that are allowed to occur at equipment interfaces, which is called the TCL. The relationship between transient control, equipment transient design and susceptibility levels is illustrated in Figure 1. The ETDL is usually stated in the specifications for electrical/electronic equipment and constitutes a qualification test level for this equipment.

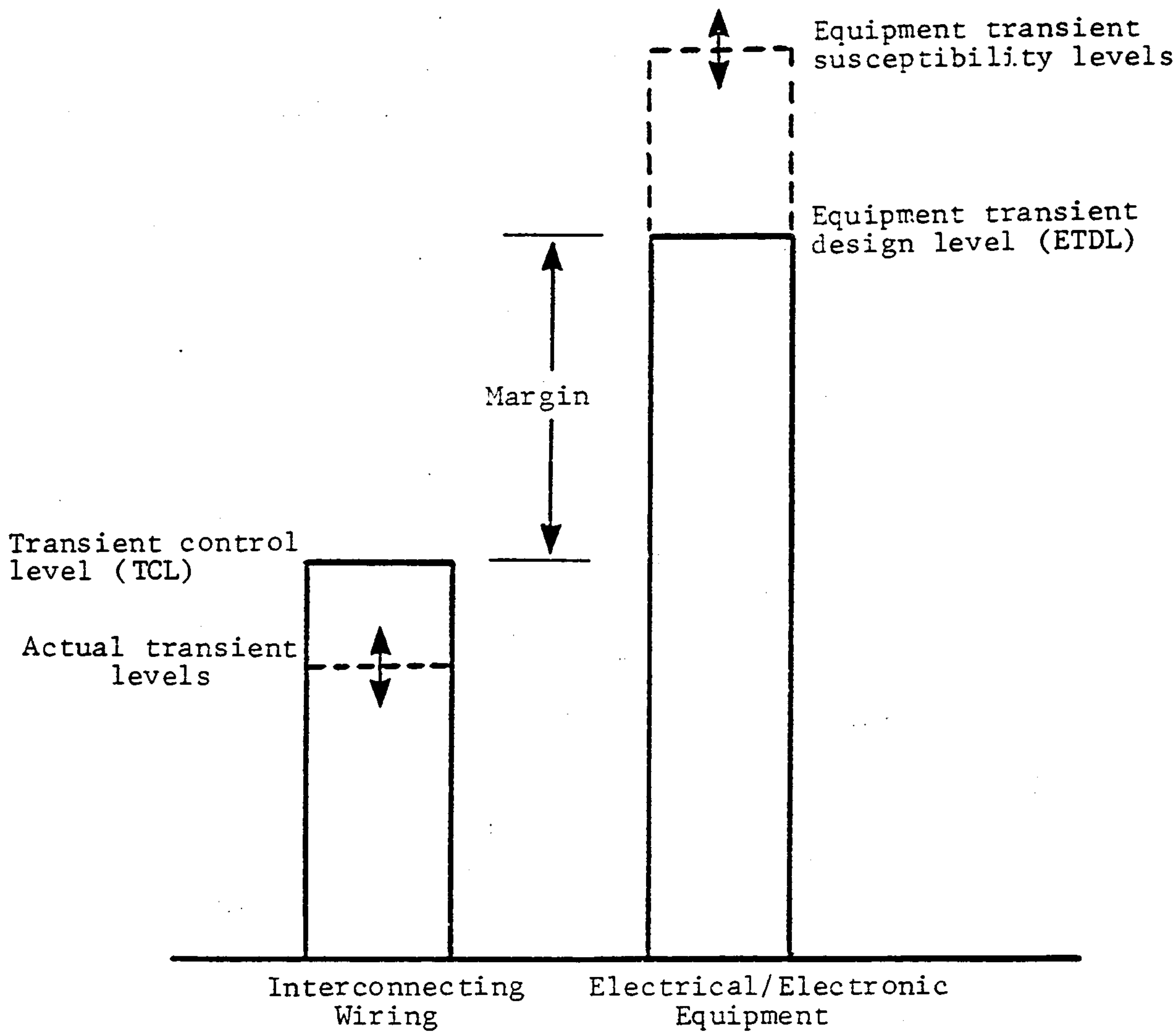


Figure 1. Relationships Between Transient Levels

Since ETDL are typically presented by use of these standardized requirements, their use greatly simplifies protection evaluation. Normally, the transient control and design levels will be established by the airframe manufacturer or system integrator, who will compare the penalties of vehicle or interconnecting wiring protection with those of equipment hardening to establish the most efficient levels.

Appendix IV contains standardized definitions of induced voltage and current waveforms and amplitudes that are representative of transients that appear at equipment interfaces. Equipment transient design levels may be selected from among the amplitude levels presented; with acceptable margins, the TCL can then be defined.

f. Design protection. To minimize the possibility of upset or damage, the ETDL should be higher than the TCL allowed to appear at equipment interfaces. In cases where the TCL plus the defined margin exceeds the transient design level, additional protection must be provided. This can be achieved by one or more of the following approaches:

(1) Reducing the TCL by reducing the actual transients appearing at equipment interfaces through design considerations (e.g. improvements in wire routing, cable and equipment shielding).

(2) Raising the ETDL by providing sufficient immunity within each piece of equipment.

(3) Providing terminal protection devices such as avalanche diodes, varistors and filters.

The approach is to optimize the use of installation design techniques, equipment immunity, and protective devices. Equipment immunity is ideally achieved through circuit/software designs that provide sufficient inherent immunity so that reliance on dedicated protection devices can be minimized.

g. Verify protection adequacy. Verify the adequacy of the protection design(s) by demonstrating that the actual transient levels appearing at wiring/equipment interfaces do not exceed the established TCL, and that the equipment can tolerate the ETDL.

(1) Verification may be accomplished by demonstrating similarity with previously proven installed systems and/or equipment, by tests, or by analysis. Appropriate margins to account for uncertainties in the verification techniques may be required as discussed in Paragraph 5. Developmental test data may be used for certification when properly documented and coordinated with the appropriate FAA Aircraft Certification Office.

Note: Except for standard design/installation items which have a history of acceptability, any new system(s), design, or unique installation should follow the additional guidelines provided herein to ensure certification compliance can be accomplished.

(2) Experience has shown, particularly on aircraft with novel and/or complex systems, that discussion of the preparation and the submittal of a certification plan early in the program is desirable. Federal Aviation

Administration concurrence of this certification plan should also be obtained. This plan is beneficial to both the applicant and the FAA because it identifies and defines an acceptable resolution of the critical issues early in the certification process. It should be understood that, as the process proceeds, analysis or test results may warrant modifications in protection design and/or verification methods. As necessary, when significant changes occur, the plan should be updated. The plan should include the following items:

(i) A description of the system(s), its installation configuration including any unusual or unique features, the operational aspects being addressed, zone locations, lightning environment, protection design level(s) and approaches.

(ii) A description of the method to be used to verify protection effectiveness. Typically, the verification method includes a combination of analytical procedures and tests. If analytical procedures are used, the methodology for verification of these procedures should be described. For further discussion see Paragraph 6.

(iii) The pass/fail criteria should be identified and will apply to testing and analysis of lightning protection of electrical/electronic equipment and systems, as follows:

(A) The ETDL should be specified.

(B) The TCL should be specified.

(C) The margin between ETDL and TCL should be defined.

(D) Interference with analog or digital data due to the transients associated with multiple strokes and the multiple burst aspect of the external environment should not endanger safety of flight.

(E) Flight safety should not be endangered by direct attachment of the lightning channel to exposed system components. Coverings (fairing, skin, cowl, etc.) should normally prevent direct attachment of the lightning channel to underlying system components. However, if a direct lightning strike attachment to a system component can occur, a complete evaluation of both direct and indirect effects will be necessary.

Note: For (A), (B), (C), (D), and (E) above, upset effects on system performance and flight safety should consider parameters such as time duration of upset, the effects of upset on the operation of the system, and the time of occurrence during the various flight modes of the aircraft. If there is no upset or if the functional upset is innocuous, then further design considerations are unnecessary. However, all observed upsets should be recorded and coordinated with the FAA. If a functional upset is not acceptable, then an improvement in the design, as described in Paragraph 3f, is necessary.

(iv) Test plans. When tests are to be a part of the certification process, plans for each test should be prepared which describe or include the following: Purpose of the test; production or test article to be utilized; article configuration; test drawing, as required; method of installation that simulates the production installation; applicable lightning zone(s); lightning simulation method; test voltage or current waveforms to be used; diagnostic methods, pass/fail criteria, and the appropriate schedule(s) and location(s) of proposed test(s).

(v) Testing sequence. The following procedural steps should be taken:

(A) Obtain FAA concurrence that the test plan is adequate.

(B) Obtain FAA detail part conformity of the test article and installation conformity of the test setup, as applicable.

Note: Parts conformity and installation conformity should be judged from the viewpoint of similarity to the production parts and installation. Development parts and simulated installations are acceptable provided they can be shown to adequately represent the electrical and mechanical features of the production parts and installation for the specific lightning tests. Adequacy should be justified by the applicant and receive concurrence from the FAA.

It is recognized, and the process is encouraged, that exploratory lightning tests are conducted early in the development cycle. These development data may be considered for certification purposes, if the development parts and simulated installations meet the criteria stated above. If it is contemplated that development test results will become candidates for certification data, adequate advance notice of this approach should be given to the FAA for their review and acceptance.

(C) Schedule FAA witnessing of the test.

(D) Conduct testing.

(E) Submit a final test report describing all results.

(F) Obtain FAA approval of the report.

4. LIGHTNING INTERACTION WITH ELECTRICAL/ELECTRONIC SYSTEMS.

a. Induced coupling.

(1) Lightning electromagnetic (EM) energy can couple into the interior of a vehicle via various penetration mechanisms (e.g. antennas, apertures, diffusion, etc.). The internal EM energy produced by lightning will be imposed upon cables, equipment, and circuit wiring. Voltage and/or current transients can result at interconnecting wiring interfaces of each individual piece of system equipment/line replaceable unit (LRU). The principal mechanisms which generate induced voltages and currents include EM fields and structural IR voltage coupling. In general, transients appearing on interconnecting wiring are determined by the external lightning environment, airframe geometry and materials, wiring methods, and physical and electrical characteristics of the interconnecting circuits.

(2) Both the currents flowing on the conductive structure of the aircraft and the transients induced on wiring and cables may show oscillatory components. The parameters of the oscillatory portion of the transient are related to the electrical length of the aircraft and/or cable and to the waveform of the excitation source. When the aircraft is exposed to a lightning transient, cables may be excited into electrical resonance and an initial oscillatory response may occur. The oscillations will damp out, in general, within 10 to 20 cycles. If the cable and/or aircraft are electrically long, this oscillatory response will dominate the total response.

(3) The oscillatory response is sometimes referred to as the homogeneous, natural or free response. It will always be present, to some extent, in the total response.

(4) The other components in the total response are referred to as the fundamental or forced responses. These responses will follow the excitation source (i.e. lightning current) waveform or will follow its time derivative, and will be significant in circuits utilizing the airframe as return and/or those installed within nonmetallic aircraft structures. Derivative responses will also be significant in circuits exposed to lightning related magnetic fields.

b. Effects of induced transients. Induced transients may be characterized by voltages impressed across or currents flowing into circuit interfaces. Equipment interface circuit impedance(s) and configuration(s) will determine whether the induced transient(s) is predominantly voltage or current. These transient voltages and currents can degrade system performance permanently or temporarily. Component damage and system functional upset are the primary types of degradation. Component damage is a permanent condition while functional upset refers to an impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state which may or may not require manual reset), which may adversely affect flight safety.

(1) Component damage.

(i) Devices which may be susceptible to damage due to electrical transients are (a) active electronic devices, especially high frequency transistors, integrated circuits, microwave diodes and power supply components, and (b) passive electrical and electronic components, especially those of very low power or voltage rating; (c) electroexplosive devices such as squibs and detonators, and (d) electromechanical devices such as indicators, actuators, relays, and motors.

(ii) Damage mechanisms for electronic components subjected to electrical transients include dielectric breakdown and thermal effects which can result in semiconductor junction, resistor, and interconnection failures.

(iii) The voltage at which dielectric breakdown occurs is a function of the material and its thickness. Breakdown can occur in all types of insulating layers if the voltage stress is high enough and applied for a sufficient time (pulse durations). In the case of electronic components, it may occur as surface breakdown or as internal breakdown. The voltage at which surface breakdown occurs is a function of the material and environmental considerations such as humidity and altitude.

(iv) Thermal effects result from transient current flow which forces the dissipation of excessive energy in the component. This is a major cause of semiconductor failure. Thermal effects can also cause resistor burnout, spotwelding of relay contacts, and detonation of electroexplosive devices.

(v) Interconnection type failures can occur due to induced electrical transients which increase the temperature sufficiently to melt metal surface connections, beam leads within integrated circuits and the wire in wire wound resistors.

(2) System functional upset.

(i) Functional upset is primarily a system problem. Permanent or momentary upset of a signal, circuit, or a system component can adversely affect system performance to a degree which compromises flight safety. In general, functional upset depends on circuit design and operating voltages, signal characteristics and timing, and system and software configuration. Systems or devices which may be susceptible to functional upset due to electrical transients include (a) computers and data or signal processing systems, (b) electronic engine and flight controls, and (c) power generating and distribution systems.

(ii) A lightning flash is often composed of a number of successive strokes, referred to as a multiple stroke flash. Although multiple strokes are not necessarily a salient factor in a damage assessment, they can be the primary factor in a system upset analysis. While a single event disturbance of input/output signals may not affect system performance, multiple signal disturbances over the flash duration may affect safety of flight. Since these sequences of transients can occur at all input/output circuit interfaces simultaneously, redundancy alone may not control upset. Control of upset effects can, however, often be achieved through a combination of circuit, systems, and software design techniques. Repetitive pulse testing and/or analysis should be carried out to evaluate the response to the multiple stroke environment. The set of waveforms defined in Appendix III represents the external multiple stroke environment and provides a practical set of waveforms for evaluation of these systems or devices. The resultant internal threat depends on the vehicle geometry, installation configurations, materials, shielding, etc. An analysis or test needs to be performed in order to obtain the resultant internal environment that would be utilized. See note on Section 2.1 of Appendix III.

(iii) In addition, in-flight data gathering projects have shown bursts of multiple, low amplitude, fast rates of rise, short duration pulses also accompanying the aircraft lightning strike process. While sufficient energy may not exist in these multiple bursts to cause physical damage effects, it is possible that indirect effects resulting from this environment may cause upset to electronic systems. The representation of this environment is a repetition of low amplitude, high peak rate of rise, double exponential pulses. A multiple burst waveform encompassing these characteristics is defined in Appendix III and is intended for use in an assessment of functional upset of the system. Again, it is required that this environment be translated into an internal environment in order to be used.

5. MARGINS AND VERIFICATION METHODS. A margin is often incorporated to account for the uncertainties involved in the verification process. This margin is defined as the difference between the ETDL and the TCL as shown in Figure 1. The magnitude of the margin required is inversely proportional to the confidence which is placed in the verification methods being used. This "confidence" is usually acquired by the extent to which it has been demonstrated that the verification techniques produce credible results. In some cases a margin ratio of 2 to 1 has been considered acceptable for an analysis that has either been supported by full scale configuration testing or is sufficiently mature to warrant confidence without testing. If verification is based on established similarity to another installation, the original margin is usually acceptable.

An acceptable margin, which consists of the difference between the ETDL and the TCL within the aircraft wiring, is an essential element in the compliance process. The analysis that provides the data which establishes the credibility of a margin may have to account for the various approximations and idealizations made in the analyses and any other factors that could produce an unacceptable error in the determination of the margin.

6. MAJOR ELEMENTS OF VERIFICATION COMPLIANCE.

a. The translation of the external environment into the internal environment involves application of elements a., b. and c. delineated in Paragraph 3. These activities, as well as those associated with the translation of the internal environment into the equipment interface currents and voltages, comprise the system level assessment of the aircraft electromagnetic (EM) response to a lightning strike and are essential elements associated with showing compliance. These activities could involve analyses using large software systems developed especially for an aircraft lightning assessment and aircraft tests that consist of injecting current (often at reduced levels) into the aircraft skin and measuring the internal environment. From the perspective of electrical/electronic equipment, the objective of this assessment is the determination of the electromagnetic environment occurring at the equipment boundaries (e.g. current/voltage waveforms and magnitudes appearing at equipment interface circuits).

b. The specific nature of the lightning induced current/voltage interface transients (actual transient levels) will be a function of the aircraft lightning interaction (e.g. external environment, attachment points) and may be determined by aircraft tests, analysis or a combination of both. The testing of a production aircraft at the full threat level defined in Appendix III is not always practical because of (a) pulse generator limitations, (b) personnel safety, or (c) aircraft availability. A purely analytical approach is difficult to substantiate and may require an appropriate conservative margin.

c. In lieu of testing a production aircraft at full threat, the injection of relatively low current levels into the aircraft skin is an alternative test approach. Three examples of test techniques for low level current injection are (a) double exponential pulse, (b) swept continuous wave (CW), and (c) damped sine wave. Experience has shown that, in general, the aircraft EM response associated with an aircraft lightning interaction involves linear processes and the result of a pulse test or a swept CW measurement or damped sine wave test conducted on a full scale vehicle at reduced levels, as discussed in Section 2.3 of Appendix III, can be extrapolated to determine the transient response to a severe strike. It may be useful to determine both open circuit voltages and short circuit currents to characterize the transient waveforms appearing at equipment interface circuits.

d. Nonlinear processes may be present (e.g. arcing between adjacent conductors, arcing across joints and apertures) during an aircraft lightning interaction. Nonlinearities, if present, would be a principal problem associated with the extrapolation process. In general, nonlinear effects tend to reduce resulting equipment interface transients but enhancement is also possible. Nonlinear effects may not be experienced during low level testing but should be anticipated and accounted for in the verification of compliance process.

e. The flow chart shown in Figure 2 outlines a process for determining the transient control and equipment transient design levels for an electrical/electronic system. These transients will usually be characterized by an open circuit (i.e. unloaded) voltage waveform, a peak voltage amplitude, and a peak short circuit current amplitude. The chart illustrates the iterative nature of the analysis and test cycle that may be needed for new designs. It shows that tests and/or analyses must usually be made early in the aircraft design cycle to obtain preliminary estimates of actual transient levels in wiring and the equipment transient design levels of system electrical or electronic components. This usually takes place during or immediately after selection of the airframe materials and interconnecting wiring methods, which constitute the basic lightning protection design. It is then possible to make initial selections of TCL and ETDL (waveforms and amplitudes), and the margins that separate them as discussed in Paragraph 5. If certain systems or components are not compatible with these levels, additional protection may be designed and applied to the airframe, interconnecting wiring or the equipment, and the process repeated until a compatibility between TCL, margins, and ETDL is found. For some systems, the initially established TCL and ETDL may have to be modified.

f. Usually, the TCL and ETDL will be established based on the capabilities of one or more key systems or components. Other components associated with the same system or subsystem are then required to conform to the established ETDL, and other interconnecting wiring is required to conform to the established TCL.

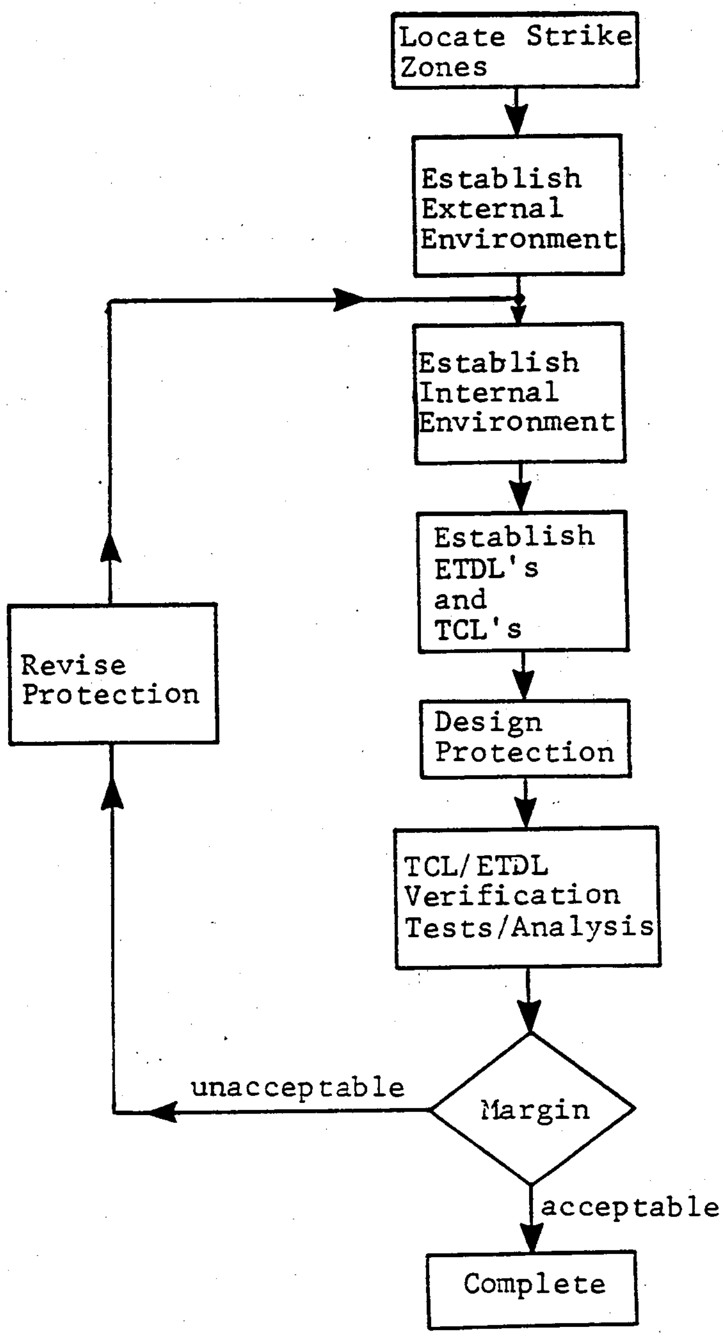


Figure 2. Iterative Process for Establishing Transient Control and Equipment Transient Design Levels and Verfication of Protection

g. Since major electrical/electronic systems are comprised of components that are distributed throughout the aircraft, verification of compliance relative to function upset involves considering the overall lightning environment to which the system is exposed. Function upset can be a particularly important issue for digital processor based systems. Systems of this nature are designed to process data using signals having a pulse format and can respond to the electrical pulses in aircraft wiring produced by lightning. The upset of a digital processor is a statistical event and single pulse testing would not be adequate.

h. Following the determination of the internal environment response to the external environment, the current/voltage waveforms and levels that comprise the equipment transient design requirements can and should be established. In general, the waveforms for the transients will be one or more of the forms shown in Appendix IV. In the case of the multiple burst environment, one possible way to provide pulses for a test would be to use a chattering relay. The chattering relay should be arranged to generate bursts of pulses at equipment interfaces similar to those resulting from the multiple burst environment.

i. When an assessment of upset is being performed by analysis and/or test, a description of the system architecture, including hardware and, where applicable, software procedures for handling data may be necessary. Such a description should clearly establish the reasons why a particular electrical/electronic system will not experience functional upset when exposed to the lightning environment.

j. The final step in the process shown on Figure 2 is verification. Here, the ability of individual systems and components to withstand the established ETDL is verified, usually by qualification tests. The adequacy of protection for interconnecting wiring is also verified, by comparison of actual transient levels with the TCL.

7. MAINTENANCE AND SURVEILLANCE.

a. When dedicated protection devices or specific techniques are required to provide the protection for a system or equipment on an installation, the periodic maintenance and/or requirements for surveillance of these devices or techniques should be defined to ensure the protection integrity is not degraded in service.

b. Items which rely on shield and connector electrical bonding, sealing materials, grounding jumpers, structural foil shield liners, etc., require an evaluation and determination that proper identification is provided to prevent degradation or accidental removal during normal aircraft maintenance that could negate or eliminate the designed protection.

c. In addition, the use of devices which may degrade with time due to corrosion, fretting, flexing cycles or other causes should be avoided where possible or dedicated replacement times identified. If sacrificial devices are utilized the capacity or number of multiple lightning strikes that any device can withstand while maintaining the design level of direct and indirect effects protection should also be identified.

d. The techniques and time intervals for evaluating or monitoring the integrity of the system protection should be defined. Built-in test equipment, resistance measurements, continuity checks of the entire system, or other means may need to be identified to provide periodic surveillance of the system integrity.

APPENDIX I - Glossary of Terms

The following are definitions of terms as they are utilized in this document.

Action integral. The action integral is a critical factor in the extent of damage. It relates to the energy deposited or absorbed in a system. However, the actual energy deposited cannot be defined without a knowledge of the resistance of the system. For example, the instantaneous power dissipated in a resistor is i^2R, and is expressed in watts. For the total energy expended, the power must be integrated over time to get the total watt-seconds (or joules). By specifying the integral $i^2(t)$ over the time interval involved, a useful quantity called the action integral is defined for application to any resistance value of interest.

Actual transient level. The actual transient level is the level of transient voltage and/or current which appears at the equipment interfaces as a result of the external environment. This level may be less than or equal to the transient control level but should not be greater.

Aircraft lightning interaction. An encounter with lightning that produces sufficient skin/structure current and/or voltages to pose a threat to the aircraft electrical/electronic systems, as a result of a direct lightning attachment.

Aperture. An electromagnetically transparent opening.

Aperture coupling. The process of inducing voltages or currents in avionic wiring or systems by electric or magnetic fields passing through apertures.

Attachment point. A point of contact of the lightning flash with the aircraft.

Beam leads. Fine conductors that make electrical connections within semiconductor devices.

Charge transfer. The charge transfer is defined as the integral of the current over its entire duration, $i(t)dt$, in coulombs.

Component damage. Component damage is that condition where the electrical characteristics of a circuit component are permanently altered so that it no longer performs to its specifications.

Continued safe flight and landing. This phrase means that the aircraft is capable of safely aborting or continuing a takeoff; continuing controlled flight and landing, possibly using emergency procedures but without requiring exceptional pilot skill or strength. Some aircraft damage may occur as a result of the failure condition or upon landing. For airplanes, the safe landing must be accomplished at a suitable airport. For rotorcraft, this means maintaining the ability of the rotorcraft to cope with adverse operating conditions and to land safely at a suitable site.

Critical. Functions whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the aircraft.

Current redistribution. The process by which electric current distribution through the entire structure changes over the duration of a lightning current pulse.

Diffusion. The process by which electric current flow spreads through the thickness of a conductive material which results in a slower increase in current density on interior surfaces as compared with exterior sufaces.

Direct effects. Any physical damage to the aircraft and/or electrical/electronic systems due to the direct attachment of the lightning channel. This includes tearing, bending, burning, vaporization or blasting of aircraft surfaces/structures and damage to electrical/electronic systems.

Equipment interface. A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an electrical/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

Equipment transient design level (ETDL). The equipment transient design level is the peak amplitude of transients to which the equipment is qualified.

Equipment transient susceptibility level. The transient peak amplitude which will result in damage or upset to the system components.

Essential. Functions whose failure would contribute to or cause a failure condition which would significantly impact the safety of the aircraft or the ability of the flightcrew to cope with adverse operating conditions.

External environment. Characterization of the natural lightning environment for design and certification purposes as defined in Appendix III.

Immunity. The capacity of a system or a piece of equipment to continue to perform its intended function in an acceptable manner, in the presence of electrical transients due to an aircraft lightning interaction.

Induced voltages. A voltage produced in a circuit by changing magnetic or electric fields or structural IR voltages.

Indirect effects. Electrical transients induced by lightning in aircraft electric circuits.

Internal environment. The fields and structural IR potentials (produced by the external environment), along with the voltages and currents induced by them.

Lightning channel hang-on. A lightning attachment which should be considered to persist at a single point for the duration of the lightning flash.

Lightning flash. The total lightning event. It may occur within a cloud, between clouds, or between a cloud and ground. It can consist of one or more strokes, plus intermediate or continuing currents.

Lightning leader. The leader is the preliminary breakdown that forms an ionized path for charge to be channeled towards the opposite charge center. The "stepped" leader advances in a series of short, luminous steps prior to the first return stroke. The "dart" leader reionizes the return stroke path in one luminous step prior to each subsequent return stroke in the lightning flash.

Lightning strike. Any attachment of the lightning flash to the aircraft.

Lightning strike zones. Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction. See Appendix III.

Lightning stroke (return stroke). A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

Line replaceable unit (LRU). The element of a system which may be removed and replaced by a line maintenance crew while the aircraft is in operational status.

Margin. The difference between the equipment transient design level and the transient control level.

Multiple burst. A randomly spaced series of bursts of short duration, low amplitude current pulses, with each pulse characterized by rapidly changing currents (i.e. high di/dt's). These bursts may result from lightning leader progression or branching, and are associated with the cloud-to-cloud and intracloud flashes. The multiple bursts appear to be most intense at the time of initial leader attachment to the aircraft (see Appendix III).

Multiple strike. Two or more lightning strikes during a single flight.

Multiple stroke. Two or more lightning return strokes occurring during a single lightning flash (see Appendix III).

Peak rate of rise. The peak rate of rise of a waveform is the maximum instantaneous slope (rate of change) of the waveform as it rises to its maximum value. Mathematically, the peak rate of rise of a function of time i(t) is the maximum value of the derivative with respect to time of i(t) and may be expressed as follows:

$$\text{Peak rate of Rise} = \text{Maximum of } \frac{d[i(t)]}{dt}$$

Restrike. A subsequent stroke in a lightning flash.

Return stroke. (see Lightning Stroke)

Structural IR voltage. The structural IR voltage is the portion of the induced voltage resulting from the product of the distributed lightning current (I) and the resistance (R) of the aircraft skin or structure.

Swept stroke. A series of successive attachments due to sweeping of the flash across the surface of the aircraft by the motion of the aircraft.

System functional upset. An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

Transient control level (TCL). The transient control level is the maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external environment.

Upset. (See System functional upset)

APPENDIX II - Location of Lightning Strike Zones

The locations of each zone on a particular aircraft may be determined as follows:

(a) Extremities such as the nose, wing and empennage tips, tail cone, wing mounted nacelles and other significant projections should be considered as within a direct strike zone because they are possible initial leader attachment points. Those that are forward extremities or leading edges should be considered in Zone 1A, and extremities that are trailing edges should be in Zone 1B. Some of the time, the first return stroke will arrive shortly after the leader has attached to the aircraft, so Zone 1A is limited to the immediate vicinity (i.e., 18 in. [0.5m] or so) aft of the forward extremity. In other cases the return stroke may arrive somewhat later, thereby exposing surfaces further aft to this environment. This should be considered if the possibility of a flight safety hazard due to a Zone 1A strike to an unprotected surface is high. Where questions arise regarding the identification of initial attachment locations or where the airframe geometry is unlike conventional designs for which previous experience is available, scale model attachment point tests may be in order.

(b) Surfaces directly aft of Zone 1A should be considered as within Zone 2A. Generally, Zone 2A (swept stroke zone) will extend the full length of the surface aft of Zone 1A, such as the fuselage, nacelles and portions of the wing surfaces.

(c) Trailing edges of surfaces aft of Zone 2A should be considered Zone 2B, or Zone 1B if initial attachment to them can occur. If the trailing edge of a surface is totally nonconductive, then Zone 2B (or 1B) should be projected forward to the nearest conductive surface.

(d) Surfaces approximately 18 in. (0.5m) to either side of initial or swept attachment points established by steps (a) and (b) should also be considered as within the same zone, to account for small lateral movements of the sweeping channel and local scatter among attachment points. For example, the tip of a wing would normally be within Zone 1A (except for its trailing edge, which would usually be in Zone 1B). To account for lateral motion of the channel and scatter, the top and bottom surfaces of the wing 18 in. (0.5m) inboard of the tip should also be considered as within the same zones.

(e) Surfaces of the vehicle for which there is a low possibility of direct contact with the lightning channel should be considered in Zone 3. Surfaces and structures which lie within or between other zones are also within Zone 3. Zone 3 areas may conduct all of the lightning currents that enter/exit from Zones 1A or 1B.

Note: Due to the unique construction and operation of rotorcraft (i.e., the vehicle may be airborne with little or zero airspeed) the swept stroke phenomenon may not be applicable, and therefore attachment points at leading edges, frontal surfaces or any lower extremities may receive all components of the flash and be within Zone 1B.

APPENDIX III - External Environment - Synthesized Waveforms

1. Idealized Component Waveforms. The waveforms defined below are idealized representations of a severe natural lightning environment for certification purposes in the assessment of the induced effects of lightning. The waveforms of components A, B, C, and D are derived from cloud-to-ground lightning discharges. Component H represents the high rate of rise effects including those from intracloud and cloud-to-cloud discharges.

These waveforms can be used as the basis for either tests or analyses of the effects of a severe lightning environment on aircraft electrical/electronic systems. Due to physical constraints, test waveforms may only be approximations of the idealized waveforms. Results from test waveforms that deviate from the idealized waveforms must therefore be analytically relatable to the idealized waveform.

Note: To address the direct effects on structures and electrical/electronic systems or components, use of the waveforms and criteria contained in Paragraph 11 of AC 20-53 is recommended. For indirect effects evaluation, not all waveforms contained in AC 20-53 are applicable and the waveforms and procedures contained in this appendix should be utilized.

a. Lightning Strike Environment. There are five current component waveforms (A, B, C, D and H) that are applied in accordance with the lightning strike zone(s) that the system is located within.

(1) Component A - First Return Stroke Current - Component A has a peak amplitude of 200 kA, an action integral ($\int i^2(t)dt$) of $2\times10^6 A^2s$ and a double exponential waveform. This waveform represents a first return stroke of 200,000 amperes and a rate-of-rise of 1×10^{11} A/s at t=0.5 μs. It has a peak rate of rise of 1.4×10^{11} A/s at t=0+. This waveform is defined mathematically by the following equation:

$$i(t) = I_o\,(e^{-at}-e^{-bt})$$

Where

I_o = 218,810 (A)
a = 11,354 (s^{-1})
b = 647,265 (s^{-1})
t = time (s)

The waveform is shown in Figure AIII-1.

(2) Component B - Intermediate Current - Component B has an average amplitude of 2 kA and a charge transfer of 10 coulombs. For analysis, a double exponential current waveform should be used. This waveform is described mathematically by the following equation:

$$i(t) = I_o\,(e^{-at}-e^{-bt})$$

Where

I_o = 11,300 (A)
a = 700 (s^{-1})
b = 2000 (s^{-1})
t = time (s)

This waveform is shown in Figure AIII-1.

(3) Component C - Continuing Current - Component C is a rectangular waveform delivering 200 coulombs of charge at a rate of between 200A and 800A in a time period of between 1s and 0.25s respectively. For analysis purposes, a rectangular waveform of 400A for a period of 0.5 second should be utilized. This component transfers a charge of 200 coulombs. The primary purpose of this waveform is charge transfer. This waveform is shown in Figure AIII-2.

(4) Component D - Restrike Current - Component D has a peak amplitude of 100 kA and an action integral of $0.25 \times 10^6 A^2 s$. This waveform represents a restrike of 100,000 amperes peak and a rate-of-rise of 1×10^{11}A/s at t=0.25 μs and a peak rate of rise of 1.4×10^{11}A/s at t=0+. The waveform is defined mathematically by the double exponential expression shown in the following equation:

$$i(t) = I_o \left(e^{-at} - e^{-bt}\right)$$

Where:

I_o = 109,405 (A)
a = 22,708 (s^{-1})
b = 1,294,530 (s^{-1})
t = time (s)

The current waveform is shown in Figure AIII-2.

(5) Component H - Multiple Burst Component - Component H has a peak current of 10 kA and a peak rate of rise of 2×10^{11}A/s at t=0+. The waveform is defined mathematically by the double exponential expression shown in the following equation:

$$i(t) = I_o\left(e^{-at} - e^{-bt}\right)$$

Where:

I_o = 10,572 (A)
a = 187,191 (s^{-1})
b = 19,105,100 (s^{-1})
t = time (s)

The current waveform is shown in Figure AIII-3.

2.0 Application.

2.1 Purposes of the Waveforms and Components.

Current Components A, B, C, D, and H together comprise the important characteristics of a severe natural lightning flash current although not all of the components may attach everywhere on the aircraft. Components A, B, D and H are described by double exponential expressions to provide the important waveshape characteristics such as rise and decay times, rate of rise, peak amplitude and charge transfer or action integral. Component C is a rectangular current pulse that transfers most of the charge in a lightning flash. Components B and C are described herein for completeness only. Indirect effects resulting from these waveforms are insignificant. The current components applicable to specific areas are described in Section 2.2 of this appendix, which relates the current components to the lightning strike zones. Guidance for locating strike zones on a particular aircraft is presented in Appendix II.

A typical cloud-to-ground lightning flash contains more than one restrike, a severe version of which is represented by Component D. In fact, flashes containing up to 24 strokes, randomly spaced, have been recorded. For protection against direct effects it is adequate to consider only one return stroke or restrike (Component A or D) because this is assumed to occur anywhere within the appropriate strike Zone (1B, 2A or 2B). However, for evaluation of indirect effects it is necessary to consider the multiple-stroke nature of an actual lightning flash, because the succession of strokes may induce corresponding pulses in data transfer circuits (for example) causing upset or cumulative damage to sensitive systems or devices. For this purpose, the following multiple stroke flash has been defined, using as a basis the definitions of Components A (first return stroke) and D (restrike).

The synthesized multiple stroke waveform is defined as an A current component followed by 23 restrikes of peak amplitude of 50,000 amperes each, as shown in Figure AIII-4. The 23 restrikes are distributed over a period of up to 2 seconds according to the following constraints:

- The minimum time between subsequent strokes is 10 ms.
- The maximum time between subsequent strokes is 200 ms.

The restrikes have waveform parameters identical to the D current component with the exception that I_o=54,703 amperes. Because most of an airframe is located within Zone 3 as well as one or more of the other zones, the multiple stroke environment is nearly always applicable. However, there may be special cases in Zone 2 where the aircraft system or subsystem and its wiring is isolated from the effects of the initial A current component and is therefore not exposed to the A component current or fields. In these special cases, the multiple stroke still applies but the first current component can be reduced from a peak of 200,000 amperes to 100,000 amperes. The applicant should coordinate this reduction in multiple stroke environment with the FAA on a case by case basis.

Component H represents a high rate of rise pulse whose amplitude and time duration are much less than those of a return stroke. Such pulses have been found to occur randomly throughout a lightning flash, interspersed with the other current components. While not likely to cause physical damage to the aircraft or electronic components, the random and repetitive nature of these pulses may cause interference or upset to certain systems. The recommended waveform comprises repetitive Component H waveforms in 24 sets of 20 pulses each, distributed over a period of up to two seconds, as shown in the multiple burst waveform in Figure AIII-5. The minimum time between individual Component H pulses within a burst is 10 μs, the maximum is 50 μs. The 24 bursts are distributed over a period of up to two seconds according to the following constraints:

- The minimum time between subsequent bursts is 10 ms.
- The maximum time between subsequent bursts is 200 ms.

Note: The multiple stroke and multiple burst environments are not intended to be applied to the full vehicle in a test. The multiple stroke and burst internal environment may be determined by testing using a single component to obtain the transfer function of interest, or to obtain the actual transient response level. The independent responses should then be repeated and spaced as described in Figures AIII-4 and AIII-5 and used repeatedly for upset assessment. An analysis of the system or equipment to be assessed should be carried out to determine pulse spacing(s) associated with systems or equipment susceptibility for the multiple stroke and burst waveforms. The resultant values should be used to space the independent responses in a sequence of 24 bursts. It should be shown by analysis or test that, by virtue of system design, architecture, hardware or software measures, there is sufficient immunity or recovery of the system from this environment. Acceptable methods are described in the User's Manual to this document.

A summary of the parameters of the idealized lightning current waveforms is given in Table AIII-1.

2.2 Zone Application of Current Components. Current Components A, B, C, D, and H and the multiple-stroke and multiple burst waveforms may be utilized for analyses or test purposes, or for combinations thereof. The appropriate current component(s) for each zone of the aircraft are shown in Table AIII-2. When the area of interest includes more than one zone, the protection assessment shall be performed utilizing the zone or zones with the most severe environment.

Zoning is used to determine the current path(s) through the aircraft and in locating the particular path(s) which represent(s) the most severe threat to the system under investigation. For most applications, the airframe is located in Zone 3 as well as one or more of the other zones (i.e. Zone 1A, 2A, or 2B). The applicable current components from Table AIII-1 are then applied together with the multiple stroke and multiple burst environments to determine the resulting internal environment.

TABLE AIII-1 - SUMMARY OF IDEALIZED WAVEFORM PARAMETERS

Parameter	Severe stroke (Component A)	Intermediate Current (Component B)	Continuing Current (Component C)	Restrike (Component D)	Multiple Stroke (1/2 Component D)	Multiple Burst (Component H)
I_o (A)	218,810	11,300	400	109,405	54,703	10,572
a (s^{-1})	11,354	700	Not Applicable	22,708	22,708	187,191
b (s^{-1})	647,265	2,000	Not Applicable	1,294,530	1,294,530	19,105,100

These equations produce the following characteristics:

i_{peak}	200 KA	4,173 A	400 A	100 KA	50 KA	10 KA
(di/dt)max (A/s) @ t = 0+sec	1.4×10^{11}	Not Applicable	Not Applicable	1.4×10^{11}	0.7×10^{11}	2×10^{11}
di/dt (A/s)	1.0×10^{11} @ t = 0.5 μs	Not Applicable	Not Applicable	1.0×10^{11} @ t = 0.25 μs	0.5×10^{11} @ t = 0.25 μs	Not Applicable
Action Integral (A^2s)	2.0×10^6	Not Applicable	Not Applicable	0.25×10^6	0.062×10^6	Not Applicable

Table AIII-2 - Zonal Application of the External Environment for Determination of Indirect Effects

Zone	Current Waveforms					
	A	B	C	D	Multiple Stroke	Multiple Burst
1A	X	X			X	X
1B	X	X	X	X	X	X
2A		X		X	X	X
2B		X	X	X	X	X
3	X	X	X	X	X	X

Note: Indirect effects resulting from Components B and C are usually insignificant.

2.3 Test Waveforms. The idealized severe waveforms in Paragraph 1 of this appendix are appropriate for analysis, but they are often difficult to apply to full scale vehicles in a test program. This is because the cost to develop and operate simulators which can deliver the severe environments may become prohibitive, especially to large vehicles such as transport aircraft. Therefore, the approach for testing full scale vehicles will frequently involve the use of waveforms other than the idealized waveforms of Section 1. However, these alternate waveforms must have the property that test results can be readily extrapolated or scaled to those which would be obtained if the vehicle were tested with the idealized waveforms. Three examples of test waveforms which can achieve the desired results are as follows:

a. The first and simplest approach is the use of current waveforms which have the same waveshape as the idealized waveforms but with a much smaller amplitude. This has the great advantage that test results (measured cable currents and voltages) obtained in this way can be scaled to threat levels by a simple scalar multiplication. This approach assumes linearity, which usually is a valid assumption, and is often conservative. The larger this scale factor becomes, however, the more uncertain is the reading. Therefore, a general guideline is to test at levels as high as possible consistent with safety and other considerations.

b. A second low level approach is the swept continuous wave (CW) method. In this approach a network analyzer system is used to obtain the frequency dependent transfer function (amplitude and phase) between the lightning current waveform and aircraft cable responses. Fourier analysis techniques are then used to obtain the temporal response to the idealized waveform. This approach also assumes linearity, and has the advantage that instrumentation and computers can be used to automate the entire package, so that the process becomes less labor intensive.

c. The third approach involves the use of a damped sinusoid generator with a rather large value of i and di/dt. This is useful because it is much less expensive to build such a generator for high levels than it is to build a high level double exponential generator. The important parameters of the peak current and its temporal derivative can then be achieved.

Such waveforms are shown as G1 and G2 of Figure AIII-6. The lower frequency sinusoid is useful for studying both aperture coupling and diffusion and current redistribution effects. The higher frequency sinusoid is useful for aperture coupling.

Test results obtained in this third approach also need to be extrapolated to the idealized waveform parameters. This becomes more difficult because it must be known if the measured coupling depends principally on the peak current amplitude or the current derivative.

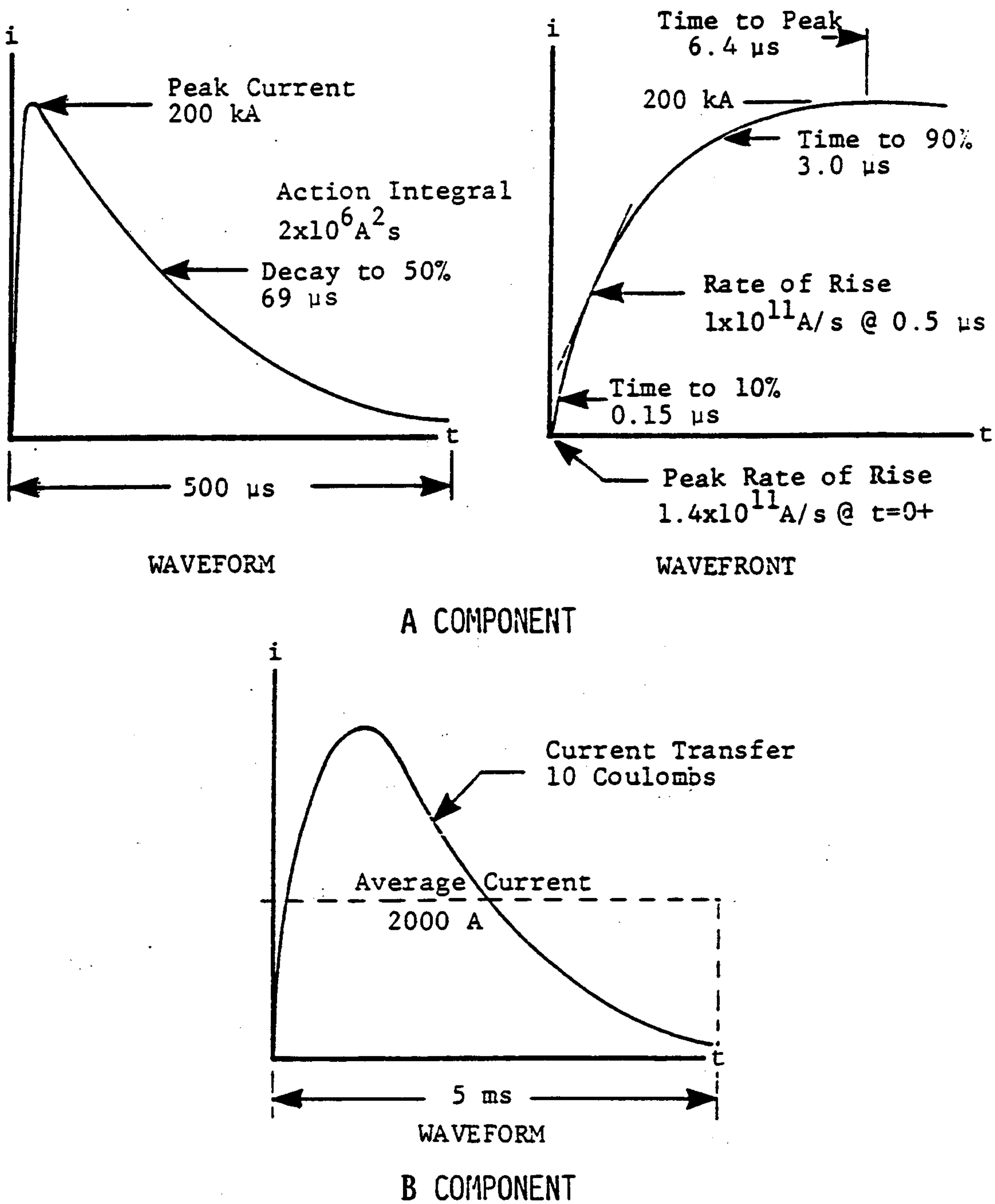
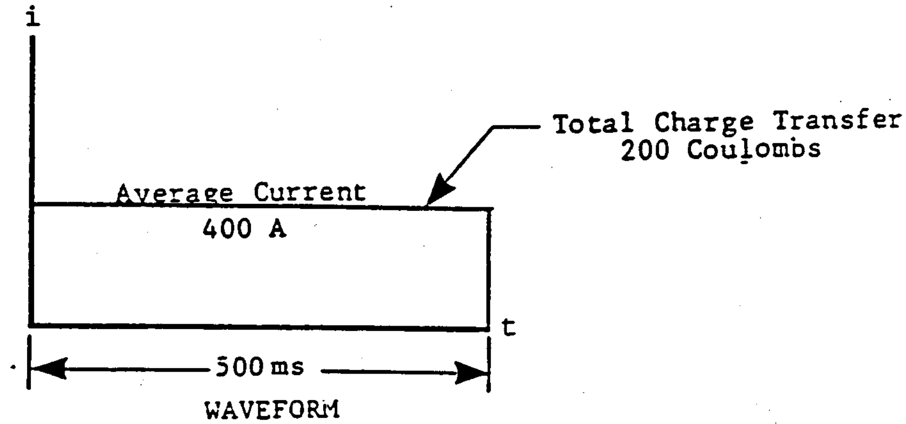
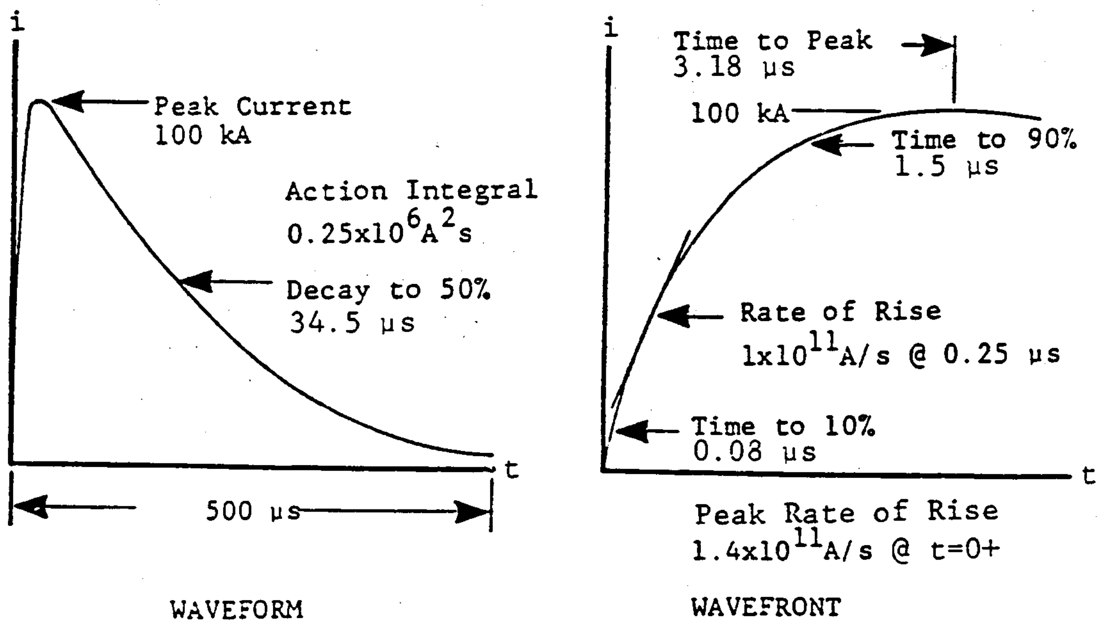


Figure AIII-1. Waveforms of Current Components A and B



C COMPONENT



D COMPONENT

Figure AIII-2. Waveforms of Current Components C and D

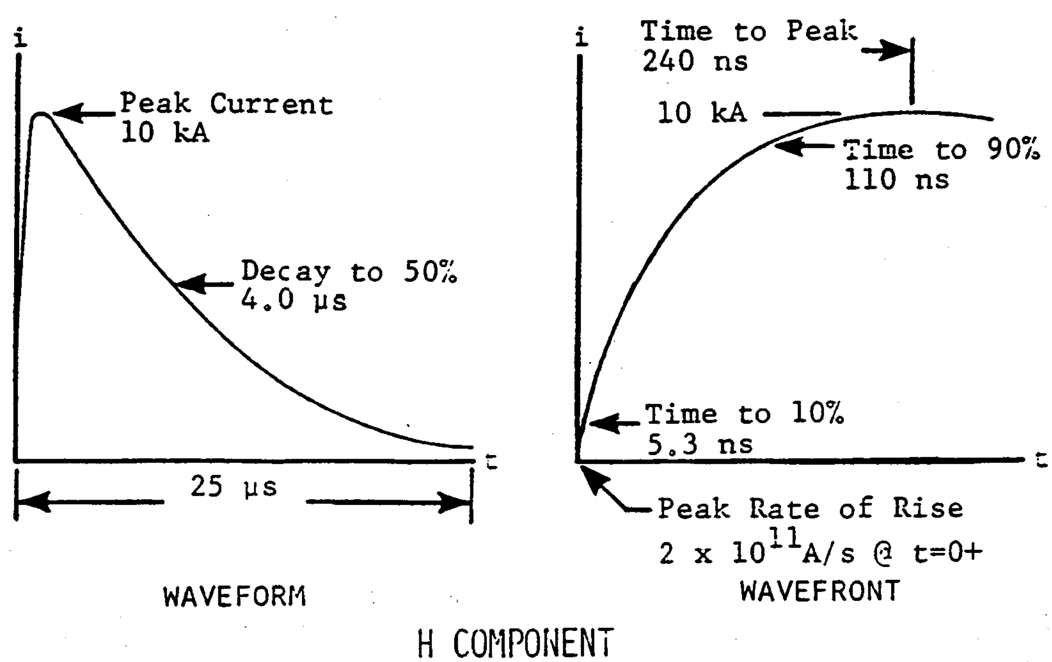
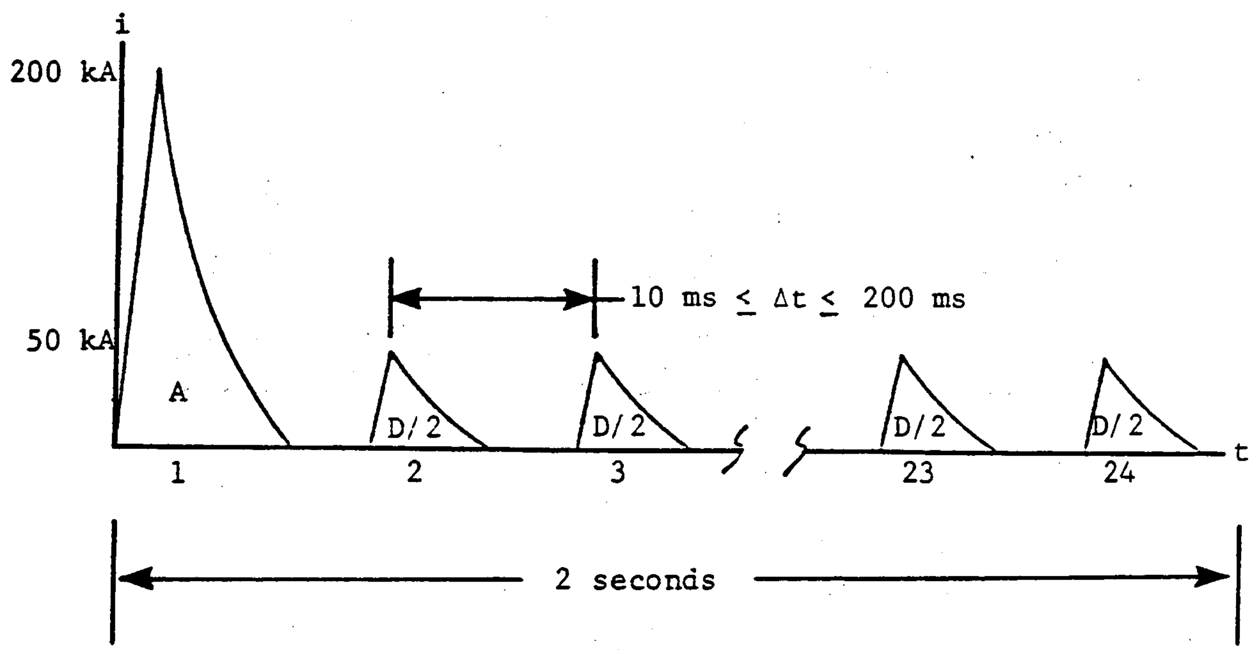
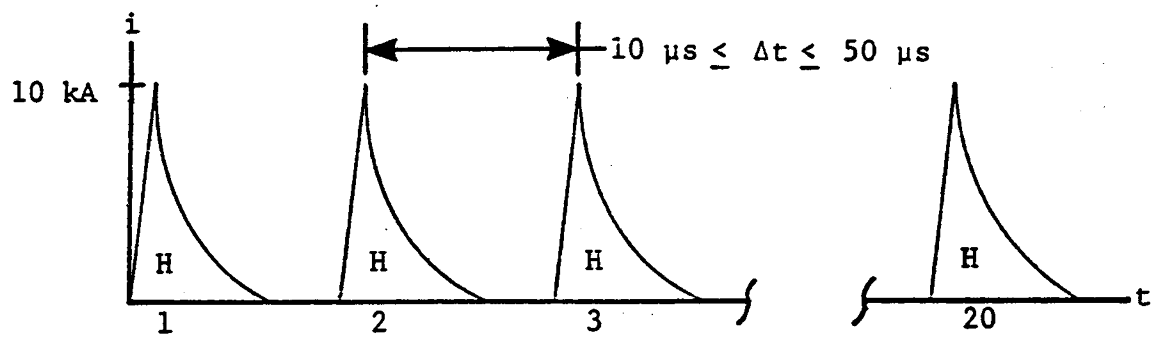


Figure AIII-3. Waveform of Current Component H .

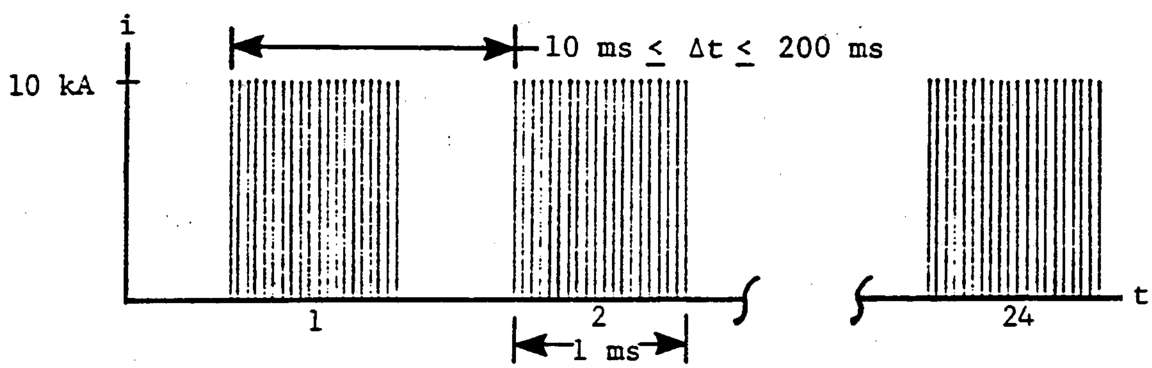


One current component A followed by twenty-three current component D's at half amplitude, as described in section 2.1, distributed over a period of up to two seconds.

Figure AIII-4. Multiple Stroke Flash



One burst is 20 pulses in 1 millisecond



Twenty-four bursts distributed over a period of up to 2 seconds

Figure AIII-5. Multiple Burst Waveform

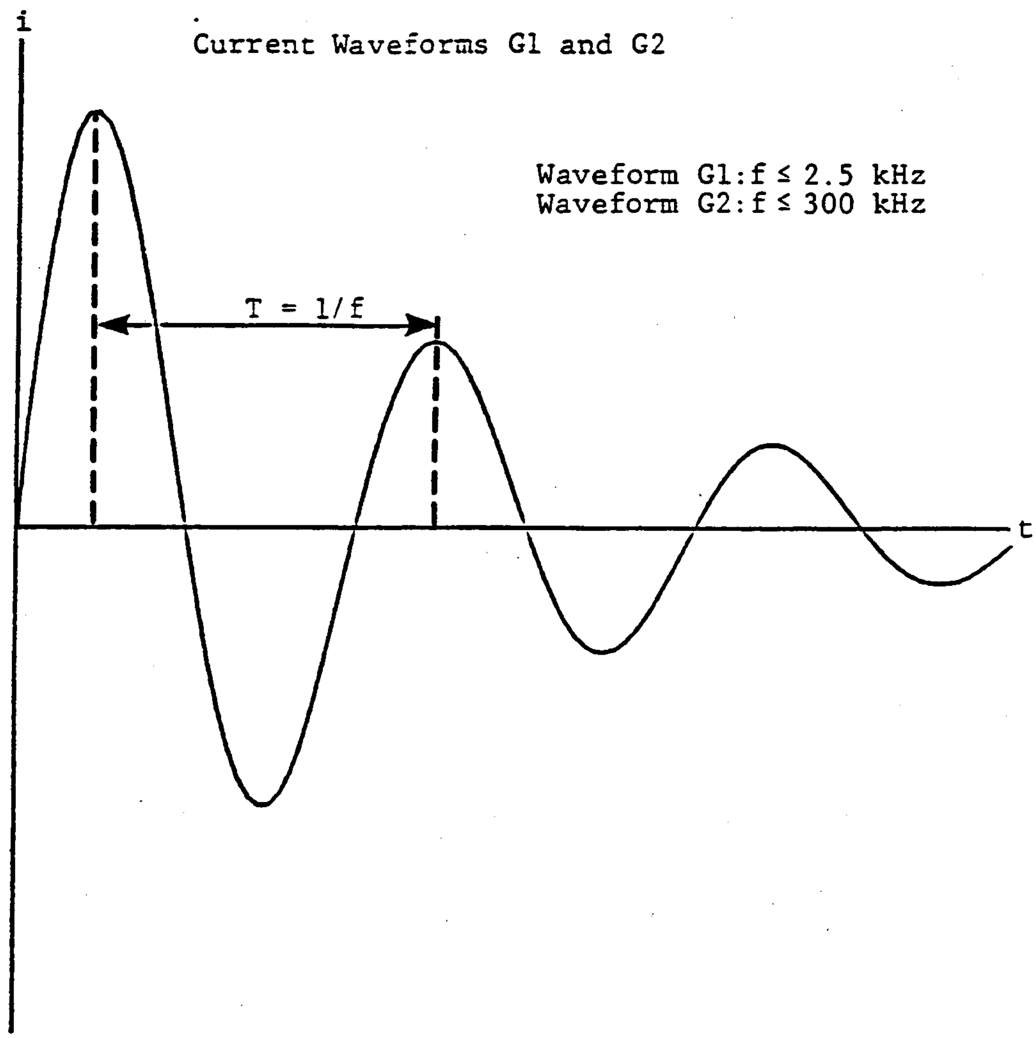


Figure AIII-6. Damped Sinusoidal Current Waveform

APPENDIX IV - Induced Voltage and Current Waveforms

1.0 Purpose. The waveforms described herein are typical of voltages and currents induced in wiring by the external environment.

The internal waveforms are the result of the external lightning characteristics being transferred internally to aircraft systems through various coupling mechanisms. Actual voltage and current waveforms which result from this transfer may be complex but can be separated into one or more of the following waveforms: (1) double exponential, (2) double exponential derivative and (3) damped sinusoidal.

Experience has demonstrated that equipment designed and tested in accordance with the waveforms defined in this appendix will tolerate a wider range of voltage and current waveshapes and frequencies than those actually induced in aircraft wiring.

The equipment transient design level to be applied to a specific system or equipment frequently must be chosen before the airframe is sufficiently detailed to know the internal environment. Many systems are designed with the intent that they will be installed in several different types of aircraft. Therefore, if a specific ETDL is not identified in the individual equipment specification, the equipment manufacturer should design and qualify the equipment to the ETDL consistent with expected use. Suggested ETDLs are identified in Table AIV-1.

2.0 Waveform 1 - Double Exponential Current Waveform. The double exponential (unipolar) current waveform is shown in Figure AIV-1. It is similar to the lightning channel return stroke current waveform (Component A) and represents that portion of the external lightning environment coupled to internal portions of an aircraft by means of structural IR voltages, and apertures.

The internal current waveforms resulting from structural IR voltages and aperture coupling generally follow the external current waveforms. The specific waveform depends upon the relative contribution of these individual coupling mechanisms.

3.0 Waveform 2 - Double Exponential Derivative Voltage Waveform. This voltage waveform, shown in Figure AIV-2 is the classical response of an open circuit to the internal magnetic field. This open circuit voltage is therefore similar to the derivative of Waveform 1. As such, the time to zero crossing (T_2) is equal to the time to peak (T_1) of Waveform 1. Waveform 2 predominates in unshielded, high impedance circuits where magnetic field coupling is the major contributor.

4.0 Waveform 3 - Damped Sinusoidal Voltage or Current Waveform. The damped sinusoidal voltage/current waveform is shown in Figure AIV-3. This waveform is one of the responses to Component A. It will be the only response to very short duration pulses such as Component H. The waveform normally appears in the early time portion of a cable response. In addition, it may also appear later if sparking occurs in the airframe.

The predominant frequencies are often associated with the natural resonances of the aircraft. However, the resonant frequencies of the voltages/currents which are induced in the cable bundles, and within equipments to which such cable bundles connect, will not necessarily be related to the aircraft dimensions.

Because of the large numbers and different lengths of interconnected cables and possible resonance modes of the aircraft, many different frequencies in the range 1 MHz to 50 MHz could be excited. Typical frequencies for this waveform are to be selected from those shown in the Figure AIV-3 table. Waveforms 3A and 3B may be applied for damage assessment by pin injection, and Waveform 3C may be applied for upset or damage assessment by bulk cable injection.

5.0 Waveform 4 - Double Exponential Voltage Waveform. This voltage waveform, shown in Figure AIV-4, is a unipolar waveform representing the potential differences that can appear between interfacing equipment ground references when lightning current flows through the aircraft structure. It represents structural IR potentials and has the same waveshape as the lightning stroke current, Component A. It often predominates in circuits that utilize the airframe as return, and in airframes fabricated of non-metallic materials.

Waveform 4 is also typical of voltages appearing in shielded conductors due to the product of shield current and resistance.

6.0 Waveform 5 - Long Duration Current Waveform. Waveforms from diffusion coupling may have slower rise times and longer durations than those of the external currents, with more conductive structures causing the longer duration waveforms. The long duration current waveform is shown in Figure AIV-5. This waveform represents diffusion and current redistribution effects found on conductors within aircraft structures.

7.0 Suggested Voltage and Current Levels. To provide a means for achieving cost effective systems, a limited number of waveforms and amplitude levels are presented for the purpose of aiding in the establishment of transient control and equipment transient design levels. The levels selected should be representative of the expected environment. Depending upon expected exposure to the lightning environment, it could be appropriate to identify different levels for particular cases.

Table AIV-1 - Suggested ETDL Voltage and Current Levels

	Waveform			
	2	3	4	5
Level	V_p (Volts) / I_s (Amps)	V_p (Volts) / I_s (Amps)	V_p (Volts) / I_s (Amps)	V_p (Volts) / I_s (Amps)
1	50/10	100/4	50/10	N/A
2	125/25	250/10	125/25	N/A
3	300/60	600/24	300/60	300/100
4	750/150	1500/60	750/150	750/1000
5	1600/320	3200/128	1600/320	1600/3k-20k

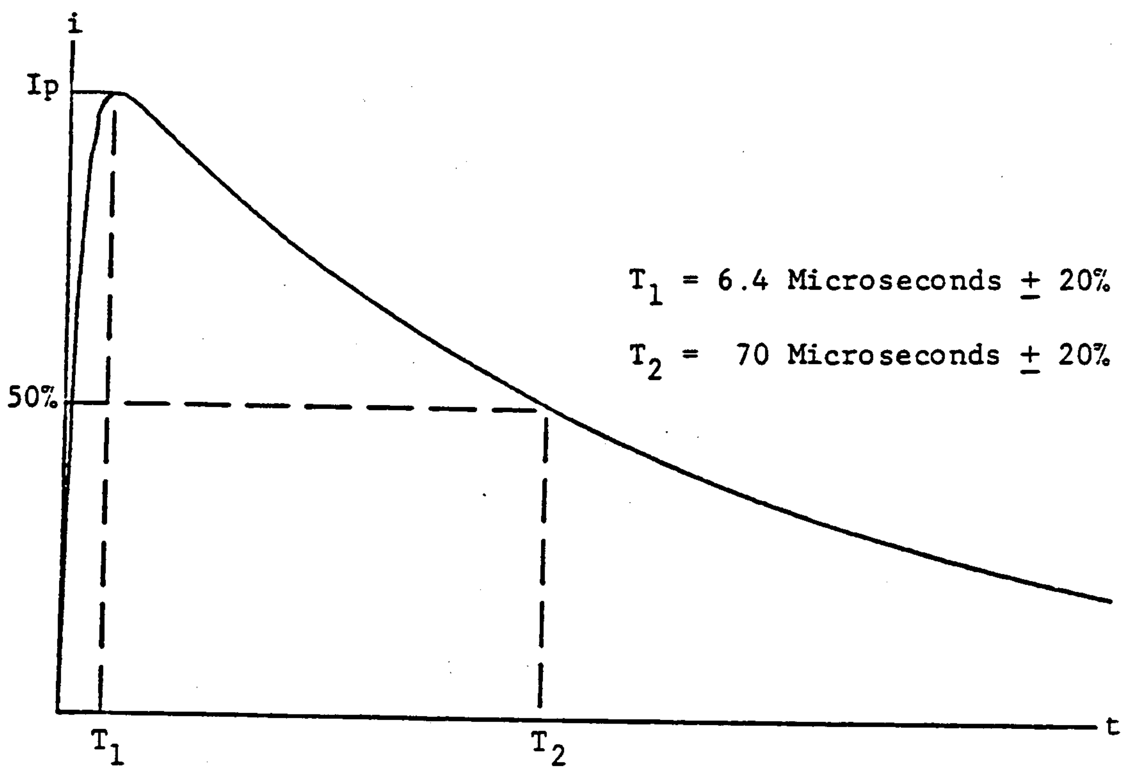
<u>Level 1</u> is typical for equipment and interconnect wiring that will be installed in a well protected environment.

<u>Level 2</u> is typical for equipment and interconnect wiring that will be installed in a partially protected environment such as an avionics bay enclosed in an aircraft composed principally of metal.

<u>Level 3</u> is typical for equipment and interconnect wiring that will be installed in a moderate environment such as the more electromagnetically open areas (e.g., cockpit) of an aircraft composed principally of metal.

<u>Levels 4 & 5</u> are for equipment and interconnect wiring that will be installed in severe electromagnetic environments. Such levels might be found in all-composite aircraft or exposed areas of an aircraft composed principally of metal, where special shielding practices have not been employed.

Table AIV-1 presents each level in terms of open circuit voltage (Vp) and short circuit current (I_s) at the output terminals of the test generator. The levels are designated Vp (volts)/I_s (amps).



Note: The amplitude of this waveform is a function of the system and its installation and may vary over a wide range.

Figure AIV-1. Waveform 1 - Double Exponential Current Waveform

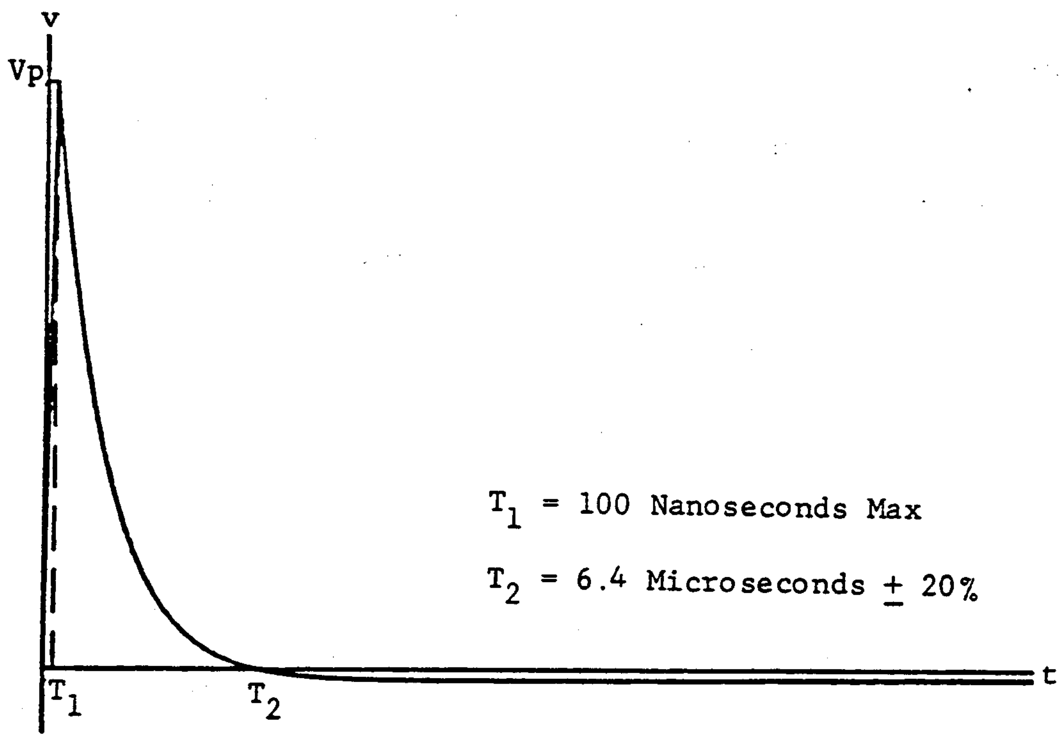
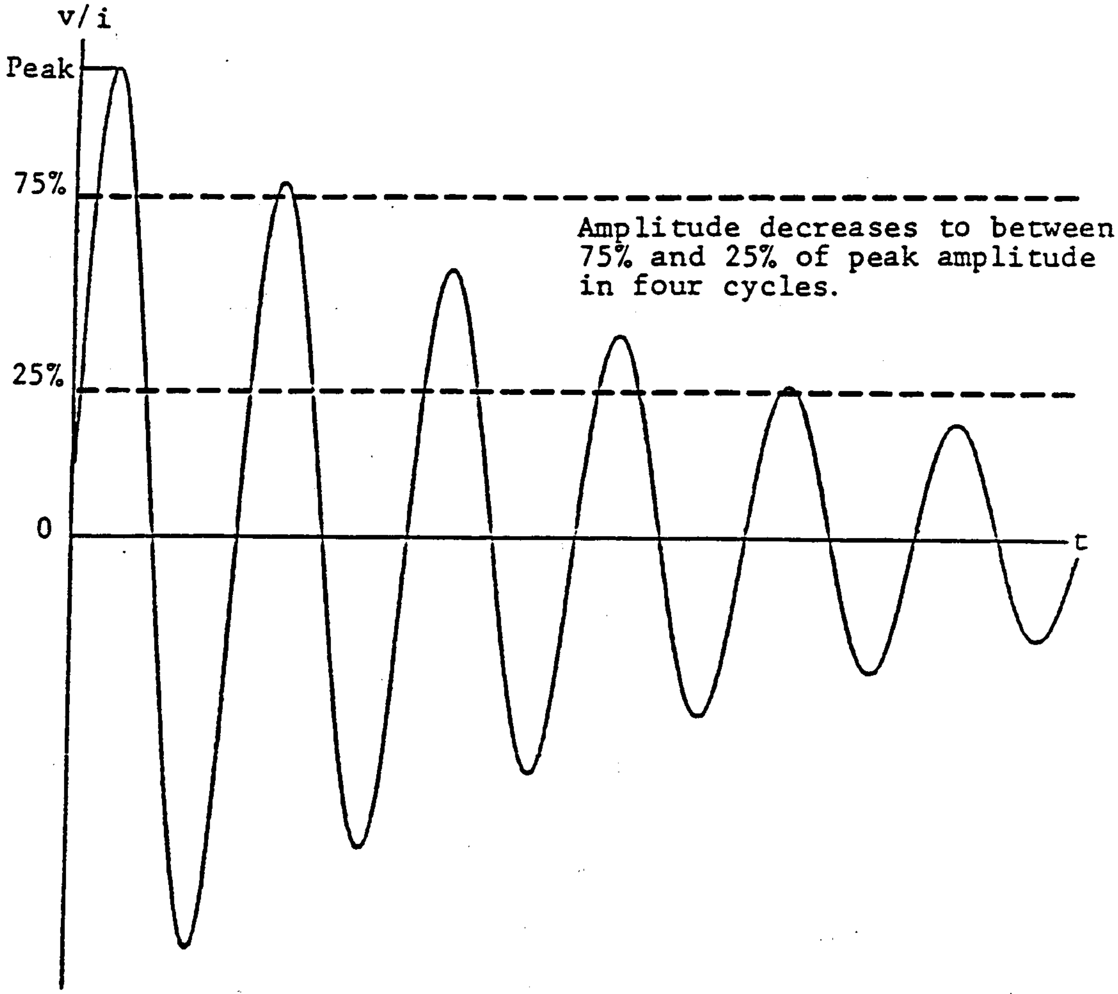


Figure AIV-2. Waveform 2 - Double Exponential Derivative Voltage Waveform



Waveform	Frequency (MHz)	Method	Purpose
3A	10 (± 20%)	Pin Injection	Damage
3B	1 (± 20%)	Pin Injection	Damage
3C	1 - 50 (as required)	Bulk Cable Injection	Upset/ Damage

Note: Specific frequency(ies) to be selected based upon system response characteristics

Figure AIV-3 - Waveform 3 - Damped Sinusoidal Voltage/Current Waveform

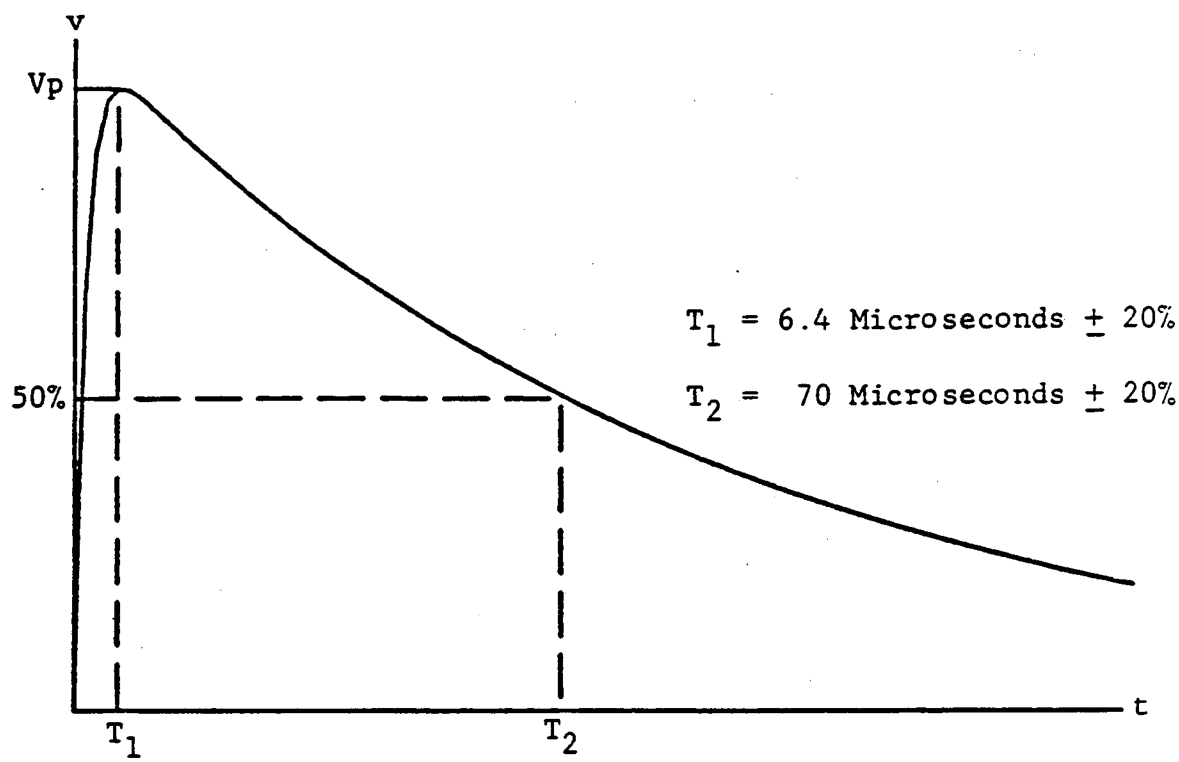
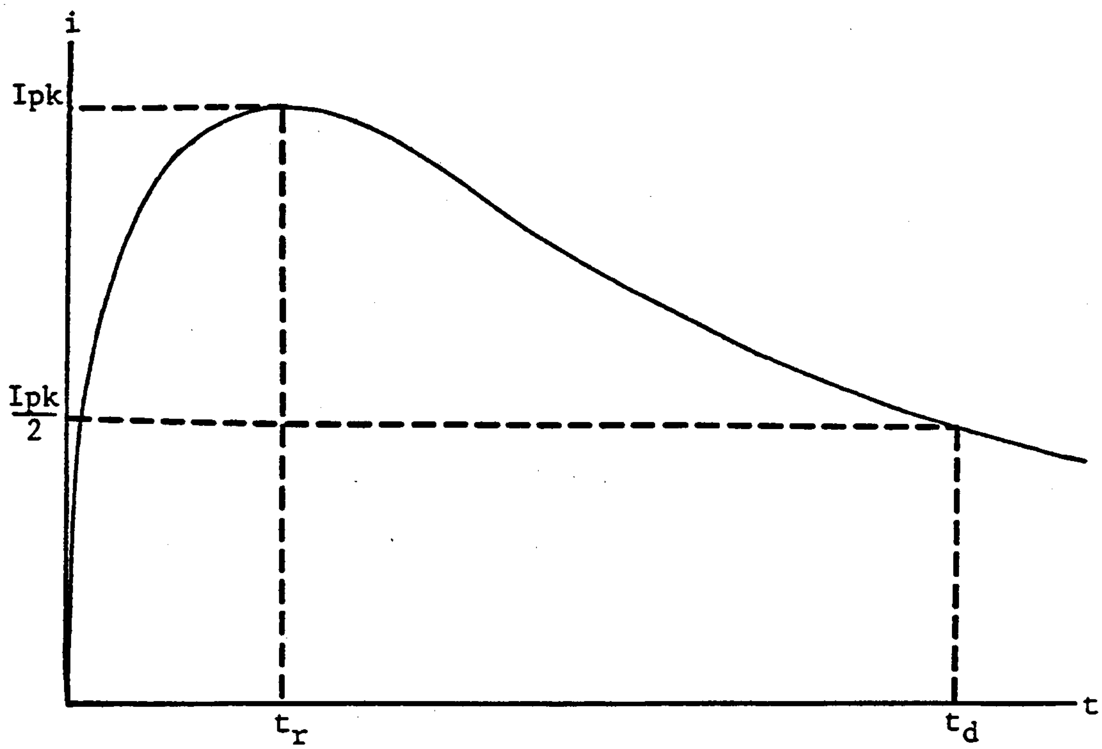


Figure AIV-4. Waveform 4 - Double Exponential Voltage Waveform



Waveform	Airframe Structural Material	Rise time t_r (us)	Decay time t_d (us)
5A	Aluminum	40	120
5B	Carbon Fiber Composite (CFC)	50	500

Figure AIV-5 - Waveform 5 - Long Duration Current Waveform

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